NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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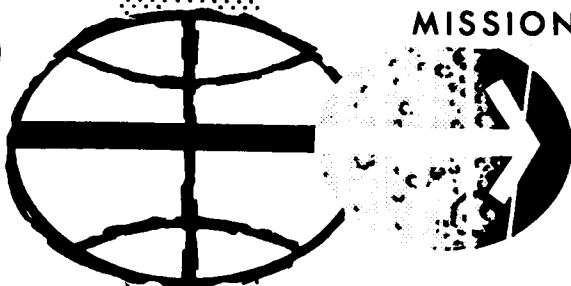# APOLLO 10 SPACECRAFT
DISPERSION ANALYSIS
VOLUME V
G&N LANDING ERROR DISPERSIONS
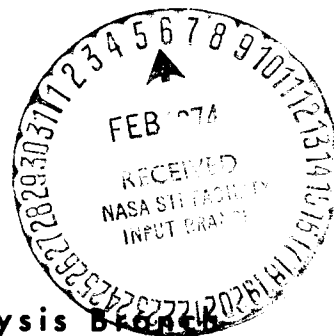
Landing Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

APOLLO 10 (MISSION F) SPACECRAFT DISPERSION ANALYSIS
VOLUME V - G&N LANDING ERROR DISPERSIONS

By John K. Burton
Landing Analysis Branch

May 13, 1969

MISSION PLANNING AND ANALYSIS DIVISION

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G&N LANDING ERROR DISPERSIONS FOR APOLLO 10 (MISSION F)

By John K. Burton

1.0 SUMMARY AND INTRODUCTION

The purpose of this internal note is to present landing disper-
sions for G&N controlled entries. The error sources considered in the
landing dispersion analysis were hardware errors, initial state vector
errors, navigation errors, and control errors. Hardware errors were
obtained from reference 1. Landing errors of ±4.50 n. mi. and
±3.80 n. mi. in the down-range and cross-range directions were obtained
from the root sum squares of the 3σ landing errors of the error sources
considered.

2.0 DISCUSSION OF ERRORS

Based on the Apollo 10 (Mission F) 1σ MSFN tracking accuracy
covariance matrix at entry interface (table I), the 3σ landing point
errors are ±0.59 n. mi. in down range and ±0.26 n. mi. in cross-range.
These landing errors are for initial state vector errors only and are
based on landing error sensitivities presented in reference 2.

The hardware errors which have the greatest effect on the landing
point are 3σ gyro bias drift rates, accelerometer bias errors, and plat-
form misalinements. Consistent with the Apollo 10 (Mission F) time line
for platform alinement 1.5 hours prior to entry interface and for average
g navigation initiation 19 minutes prior to entry interface, the root-
sum-square (RSS) landing point errors caused by the hardware errors
considered are ±4.40 n. mi. down range and ±3.53 n. mi. cross range.

Variations in landing caused by atmospheric density, CM weight,
and CM L/D variation are negligible because the CM L/D is within the
range required to assure controlled entry.

The CMC navigation logic uses a relatively simple numerical
integration technique that results in a bias navigation error (ref. 2).
This bias error gives typical landing errors of 0.20 n. mi. and
0.02 n. mi. in the down-range and cross-range directions, respectively.
It is also noted in reference 2 that a random landing error results

from CM control errors. Based on 191 entry simulations, the 3σ control error standard deviations are 0.72 n. mi. in the down-range direction and 1.38 n. mi. in the cross-range direction.

The RSS of the 3σ landing errors for each of the error sources considered result in landing dispersions of ±4.50 n. mi. and ±3.80 n. mi. in the down-range and cross-range directions, respectively.

3.0 ENTRY GUIDANCE PERFORMANCE

One of the most critical parameters used in the entry guidance logic is altitude rate. Large uncertainties in this parameter at entry interface can cause high entry loads or uncontrolled skips out of the atmosphere. The best estimate of the allowable altitude rate uncertainty is ±200 fps. Although this allowable uncertainty may be updated, it will not change significantly. The 3σ uncertainty in altitude rate at entry interface caused by MSFN tracking inaccuracy is ±3.91 fps. This uncertainty is relatively small and can be handled easily by the entry guidance.

The deviations of actual state vectors at entry interface are presented in table II. The deviations are relatively small and will not significantly affect the performance of the entry guidance in attaining the target point. For instance, the standard deviation of the flight-path angle at entry interface is 0.065°. This deviation is well within the entry corridor bounds of +1.25° and -0.75° about the nominal -6.5° flight-path angle for the lunar return speed. The covariance matrix of state vector deviations at entry interface is presented in table III. Total heat and heating rate deviations caused by errors, uncertainties, and deviations are considered minor and will cause no problem.

4.0 CONCLUSION

In summary, the RSS 3σ landing errors of the error sources considered result in landing dispersions of ±4.50 n. mi. and ±3.80 n. mi. in the down-range and cross-range directions, respectively. Deviations in the state at entry interface will not cause significant heating or performance problems.

TABLE I. - ONE-SIGMA COVARIANCE OF CSM[a]

ENTRY UPDATE PROPAGATED TO ENTRY[b]

[Entry minus 1 hour]

	U^c, ft	V^d, ft	W^e, ft	$\dot{U}$, fps	$\dot{V}$, fps	$\dot{W}$, fps
1	1.4204682+06					
2	-2.5147619+05	2.3064465+06				
3	-4.5184957+04	1.9848775+05	4.7796785+05			
4	4.9228926+02	-1.9449496+03	-1.4444184+02	1.7037807+00		
5	-1.0755304+03	-1.5848637+02	1.9496076+01	-8.4924516-02	8.7231232-01	
6	7.5465269+02	-8.7325323+02	-1.5346350+03	8.5221028-01	-4.8577971-01	6.1413188+00

[a]Earth central body.

[b]Data for this table were taken from reference 3.

[c]U is radial direction.

[d]V is down-range direction.

[e]W is out-of-plane direction.

TABLE II.- ACTUAL DEVIATIONS AT EI AFTER

LAST TRANSEARTH MIDCOURSE

Parameter	Nominal	Mean	Standard deviation	Low values	High values
Actual entry flight-path angle, deg	-6.487	-6.486	0.065	-6.657	-6.306
Actual deviation in entry speed, fps	0	1.4	5.2	-12.9	17.4
Actual deviation in entry longitude, deg	0	-.02	.60	-2.11	1.39
Actual deviation in entry latitude, deg	0	.01	.22	-.63	.51
Actual deviation in entry azimuth, deg	0	.01	.49	-1.41	1.15

TABLE III.- COVARIANCE MATRIX OF STATE DEVIATION AT EI

	V, ft	W, ft	U, ft	$\dot{V}$, fps	$\dot{W}$, fps	$\dot{U}$, fps
(V)	2.4093797×10^9					
(W)	1.1937141×10^8	6.7694451×10^9				
(U)	2.9230501×10^3	-4.7246094×10^3	1.5203059×10^{-2}			
($\dot{V}$)	-2.3875396×10^5	-1.3874212×10^5	$-1.8403649 \times 10^{-1}$	5.0474667×10^1		
($\dot{W}$)	-4.9356814×10^5	-2.7302120×10^7	1.9027708×10^1	5.4231607×10^2	1.1012981×10^5	
($\dot{U}$)	-2.0685786×10^6	-2.0857777×10^5	-2.4527728×10^0	2.2101737×10^2	8.4697653×10^2	1.8061258×10^3

5.0 REFERENCES

1. Nolley, Joe W.: Error Source Data for Dispersion Analyses. MSC IN 68-FM-297, December 13, 1968.

2. Graves, Claude A.: Reentry Error Analysis for the Apollo Lunar Landing Mission. MSC IN 68-FM-36, February 14, 1968.

3. Mathematical Physics Branch/MPAD: Apollo Mission F (AS-505/CSM-106/LM-4) Spacecraft Dispersion Analysis, Volume I, Navigation Error Analysis. MSC IN 69-FM-83, April 14, 1969.